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Dealing with toxic impacts in life cycle assessment

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Portland dose-response workshop, 14 November 2004

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Emission to damage

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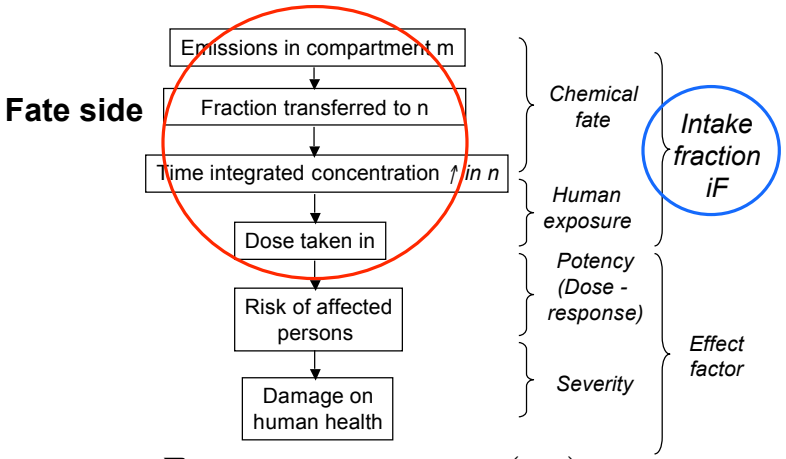

$$iF = \frac{\sum_{people,\,time} \text{intake of pollutant by an individual } (mass)}{\text{mass released into the environment } (mass)}$$

(ES&T, 2002)

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Ranges in intake fraction outdoor air emissions

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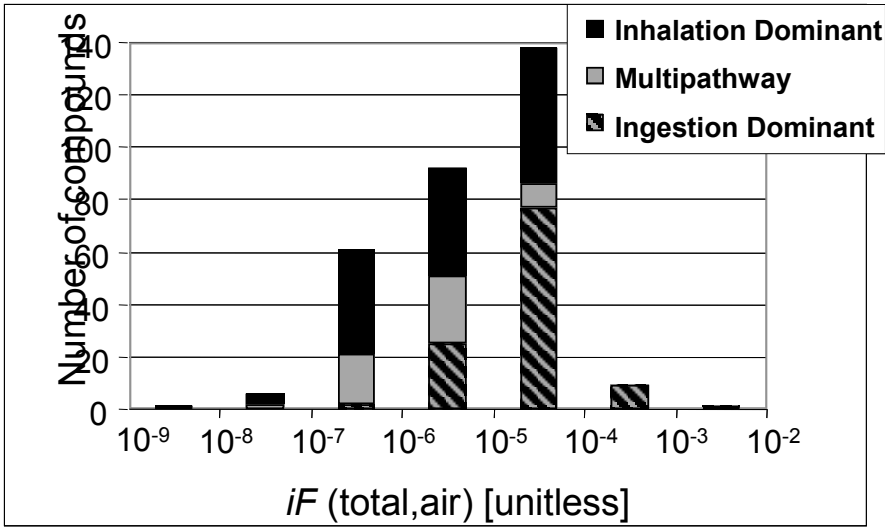

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Human health framework

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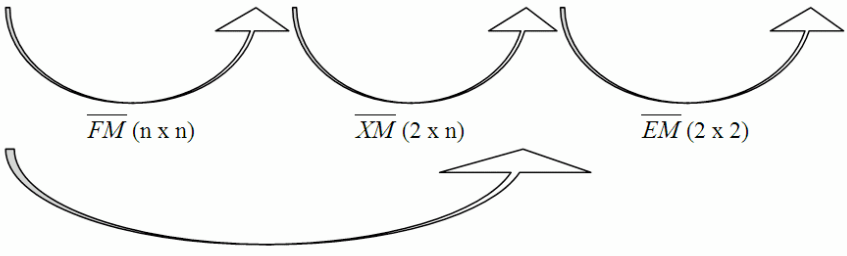
$\vec{S}$ Source (n) [kg/day]	$\vec{M}$ Mass (n) [kg]	$\vec{I}$ Intake flow (2) [kg/day]	$\vec{N}$ Impact flow (2) [No. of cases/day]
$\vec{S}$ Mass emitted [kg]	$\int \vec{M} dt$ Time integr. mass [kg-day]	$\vec{I}$ Mass intake [kg]	$\vec{N}$ Impact [No. of cases]



$\overline{FM}$ (n x n) $\overline{XM}$ (2 x n) $\overline{EM}$ (2 x 2)

$$\overline{iF} = \overline{XM} \cdot \overline{FM} \quad (2 \text{ x } n)$$

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Emission to damage a) Human health

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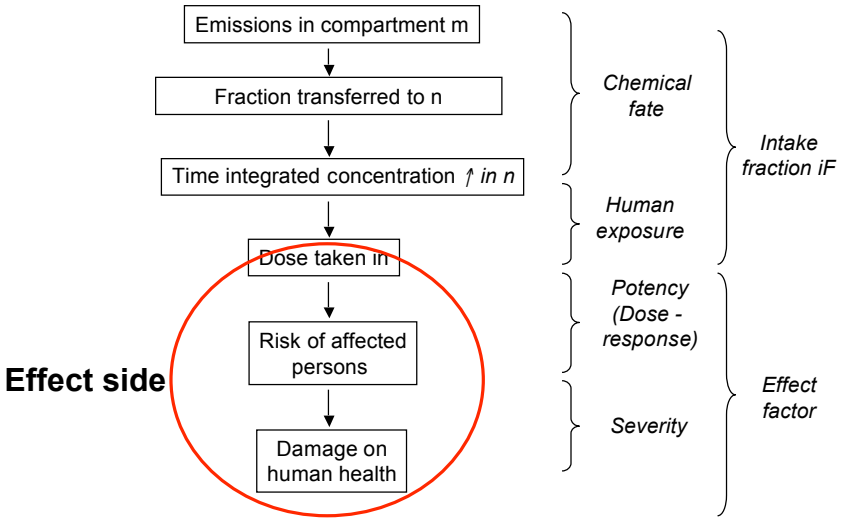

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ILSII panel 95: Limitations of RfD for an application to LCIA

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Burke et al., 1996 (ILSII panel) recommended to use the NOAEL or response doses rather than RfD,

since the comparison of toxic releases based on their RfD can be biased, because:

- **The UFs applied to derive the RfD are conservative.**
- **The response level associated with the No Observable Adverse Effect Level (NOAEL) can change.**
- **The RfD is dependent on the experimental design.**

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ILSI Panel
Severity: Burke et al., 1996

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Subcategory 1 (Irreversible/life-shortening effects)	*Subcategory 2* (Maybe reversible /maybe life-shortening)	*Subcategory 3* (Generally reversible/generally not life-shortening)
Cancer Reproductive effects Teratogenic effects Acute fatal or acute severe and irreversible effects (i.e. fatal poisoning) Mutagenicity	Immunotoxicity Neurotoxicity Kidney damage Liver damage Heart disease Pulmonary (i.e. asthma)	Irritation Sensitization Reversible acute organ effects (i.e. GI inflammation)

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Dose - response / potency
SETAC-EU WGIA2

(working group on impact assessment)

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Type of indicator	Key Advantages	Key Issues	LCIA application
Regulatory potency measures, ADIs, RFDs, RFCs	Widely adopted risk assessment	Inconsistent conservatism, adverse risk rather than low-dose risk	Hertwich Huijbregts Goedkopp and Spriensma, partly Hauschild et al.
Slope factors based on benchmark doses, such as βED10	Introduced to provide a consistent basis for low-dose risk response carcinogens and non-carcinogens	Not widely adopted yet while implicit in most measures for non-carcinogenic effects	(Crettaz et al., 2001a, b) 1000 substances
Acute toxicity data, such as LD_{50}s and LC_{50}s	Widely available data.	Relative acute to chronic importance is unlikely to be consistent across chemical emissions.	Partly used in (Hauschild et al., 1997). Extrapolations acute to chronic data are widely adopted.

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Severity based indicators SETAC-EU WGIA2

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Type of indicators	Key Advantages	Key Issues	LCIA application
Qualitative indicators			
ILSI classification: Health endpoints allocated to 3 categories (Burke et al., 1996)	Somewhat homogeneous group of health effects with different levels of severity.	3 categories allows rough severity ranking only. Weighting requires value judgement.	Demonstrated by Owens (2000) and adapted by Crettaz et al. (2001b)
Quantitative indicators			
Disability Adjusted Life Years (DALY), based on (Murray and Lopez, 1996), supported by WHO, World Bank	Allows aggregation of mortality and morbidity) on a single cardinal scale.	No final consensus on weighting factors for different health effects. DALY not always possible	(Hofstetter), Eco-indicator '99 (Goedkopp and Spriensma (Crettaz et al. 2001a, b) present data for over 1000 chemicals.
Quality Adjusted Life Years (QALY) (e.g. Rosser, 1987)	(similar to DALY)	(similar to DALY)	not currently used in LCIA but in RA
Years Of Life Lost (YOLL)	aggregation of different mortality effects	Giving the same value to any life year:a value choice not cover non-fatal effects.	key indicator in ExternE-type applications (European Commission, 1999)

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Human toxicity recommendations A stepwise procedure (SETAC-EU WGIA2)

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1. Toxicological potency indicators such as ED10 as a minimum default

- While methods in their infancy, it is encouraged to take into account relative severity,

--> 2. YOLL 3. DALY/QALY

Key tasks:

- Lack of toxicity data

- Population density

- Aggregation linked to severity authorised by international body

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Points to be adressed

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- How to derive dose-response information for a large number of chemicals (eventually screening and advanced approaches) ?
- Relevance: How to relate the animal endpoint to human endpoints and eventually YLL, YLD ?
- How to make enpoints comparable, using e.g. DALY's ?

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Points to be raised

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- Extrapolations chemical with acute, QSAR: shows that restricted !!
- Severity: as soon as impact scores are added, a weighting is performes with equal severity. If all endpoints are kept separate → OK
- Interesting to come to DALY because: upper limit, put into perpective to observed damages
- Always come back to initial goal of comparison → kg equ substance to communicate
- The way it can be used in practice: BMW

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Carcinogens (EPFL&Harvard) The ED10 approach

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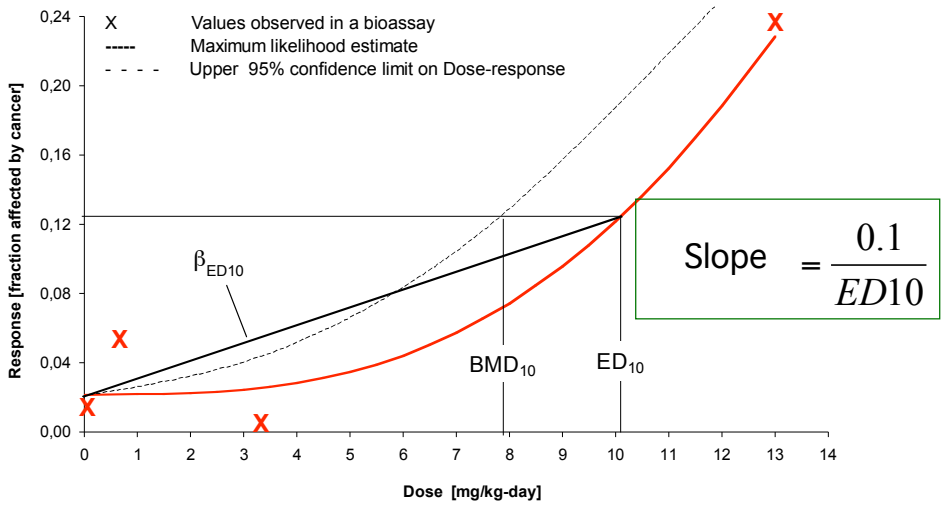
For comparative assessment: *Effect Dose 10% over background*



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Linearity at low doses ?

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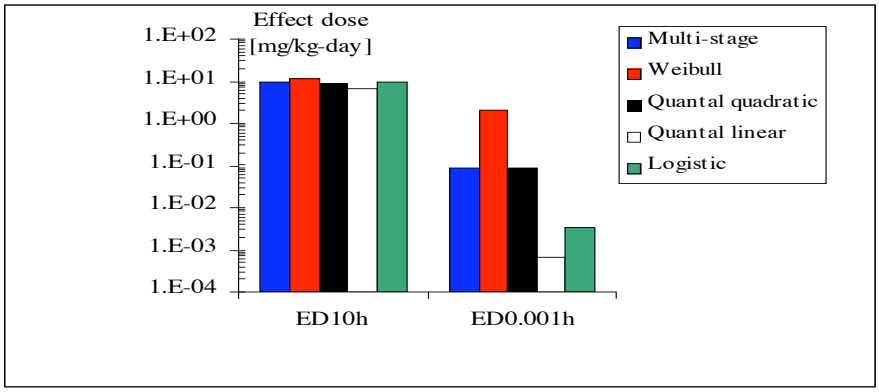

Below 10% effect, the answer depends only on the model retained ! Impossible to predict (non-) linearity on the basis of bioassays !

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EVALUATION from the tumor dose TD_{50a}

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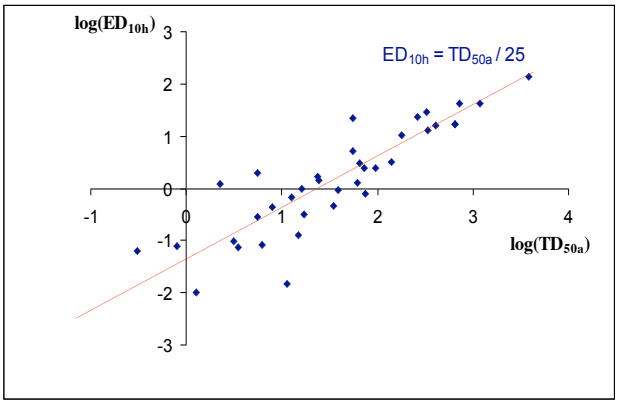
• The TD_{50s} - ED_{10s} correlation is relatively high (n=37; R^2=0.75)

IRIS



GOLD

• Apply to 671 substances with a TD_{50a} in the CPDB [Gold and Zeiger, 1997]
==> Slope factors: 10^{-4} ---> 10^{4} [Risk/ mg/kg-day]: Factor 100 million !

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Correlation ED10 - TD50 data provided for 670 carcinogens

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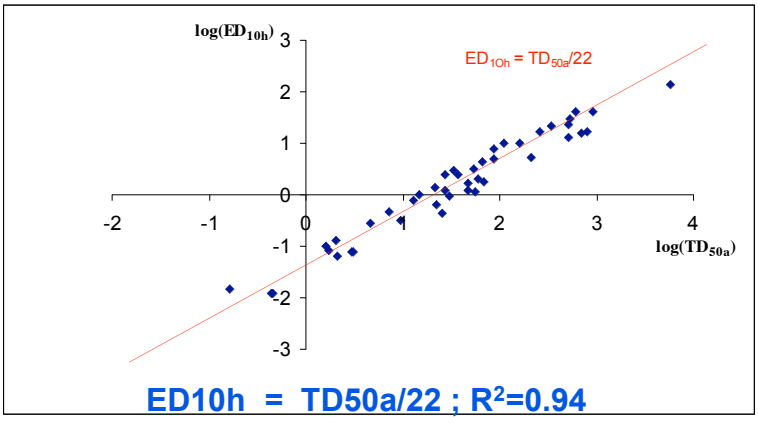
IRIS



IRIS

Dose-response: 80% variation between databases, against 20% between TD50 and ED10. Use the best database for TD50.

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Correlation β(ED10) - q1*

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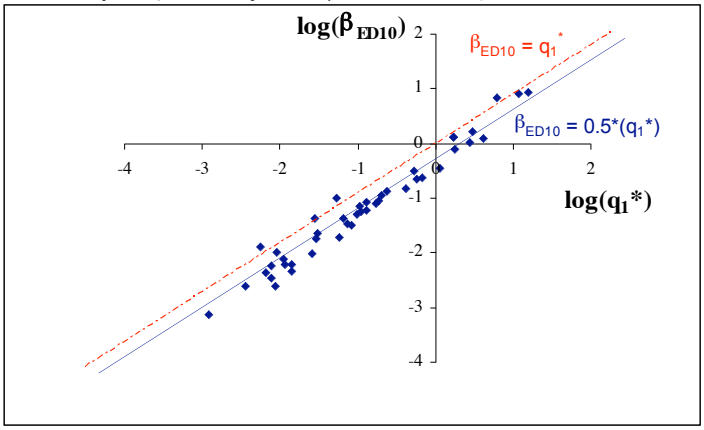
q_1^* and β_{ED10} are strongly correlated (R^2 = 0.94): q1* reflects a linear assumption !!

On average, q_1^* is higher by a factor 2 (no more than a factor 10)



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EXTRAPOLATION from the lethal dose LD_{50a} (cancer)

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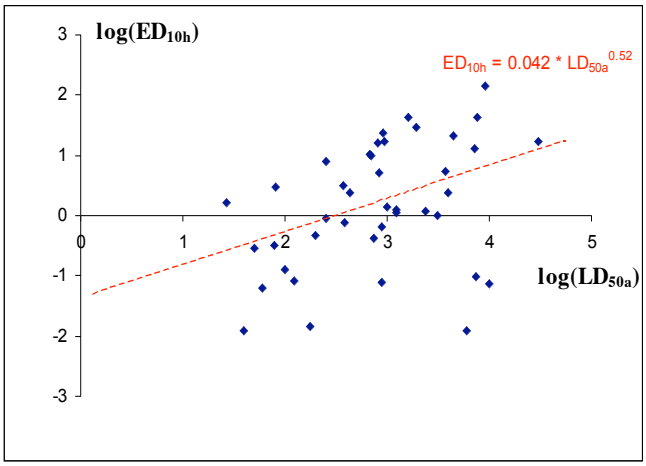
The LD50s - ED10s correlation is rejected (n=41; R^2=0.14)
==> No assessment of data-poor substances is provided!



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Evaluation of non cancer

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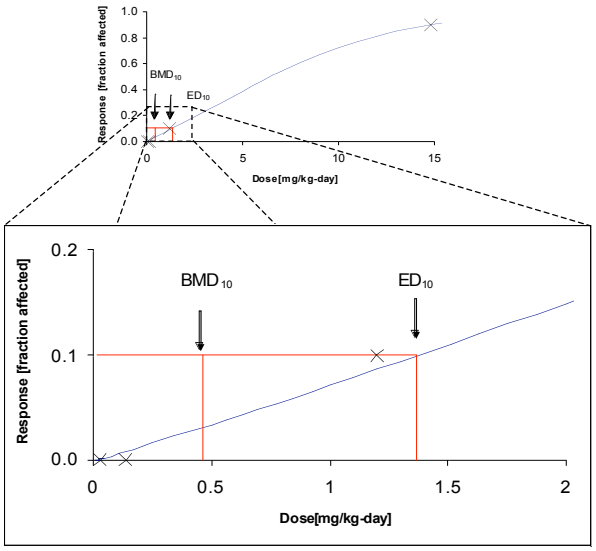

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Comparison of ED10h and benchmark dose BMD10h

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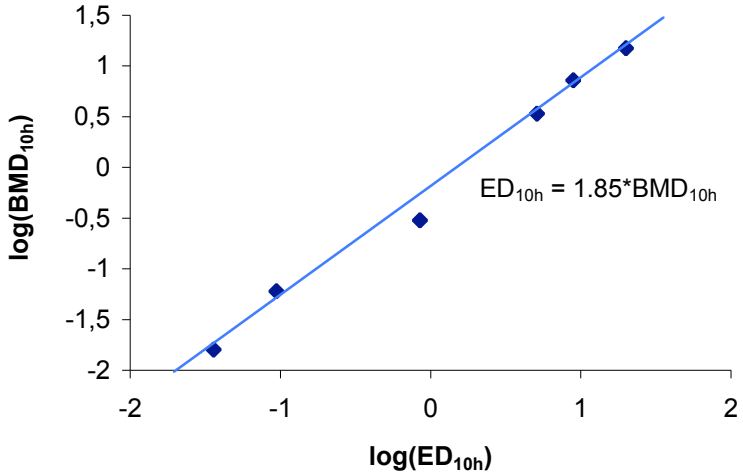
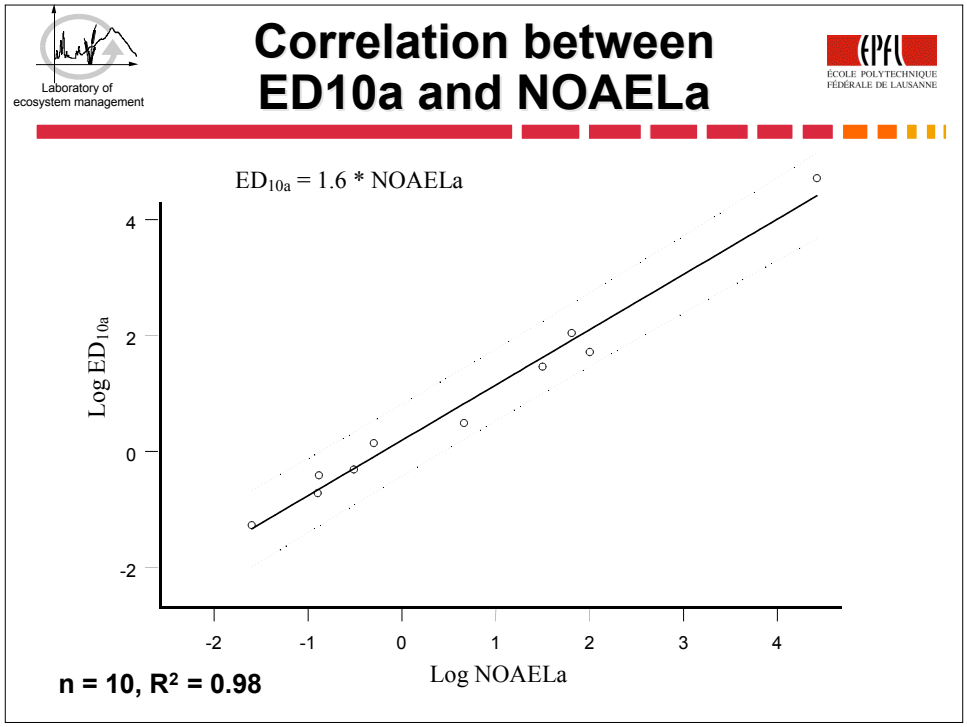


(n = 6; R^2 = 0.98)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Correlation between ED10a and NOAELa
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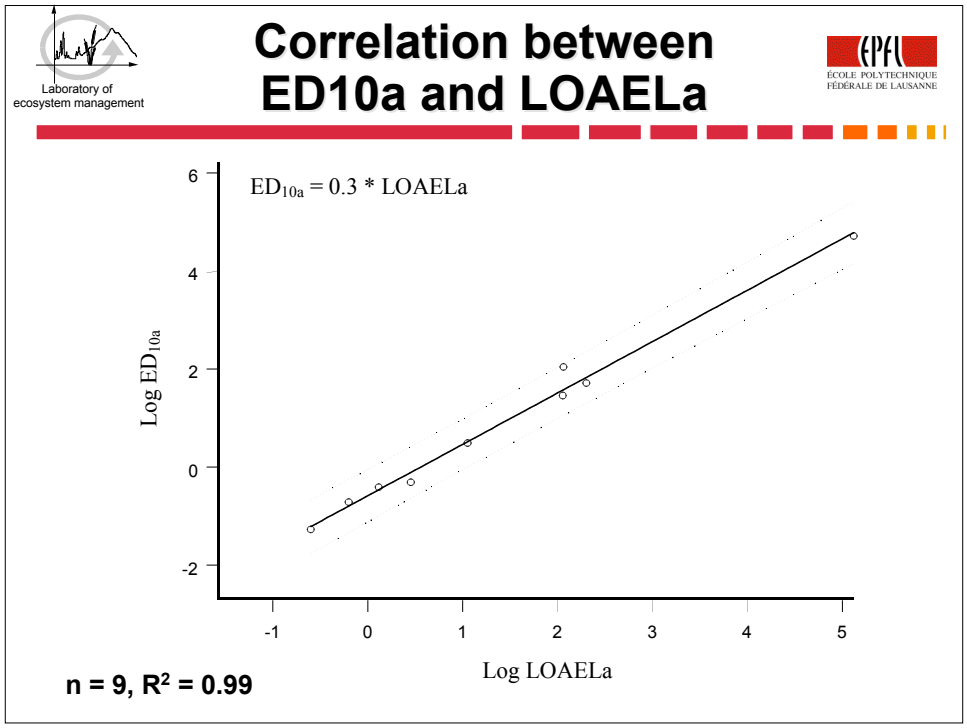
ED10a = 1.6 * NOAELa
Log ED10a
Log NOAELa
4
2
0
-2
-2
-1
0
1
2
3
4
n = 10, R² = 0.98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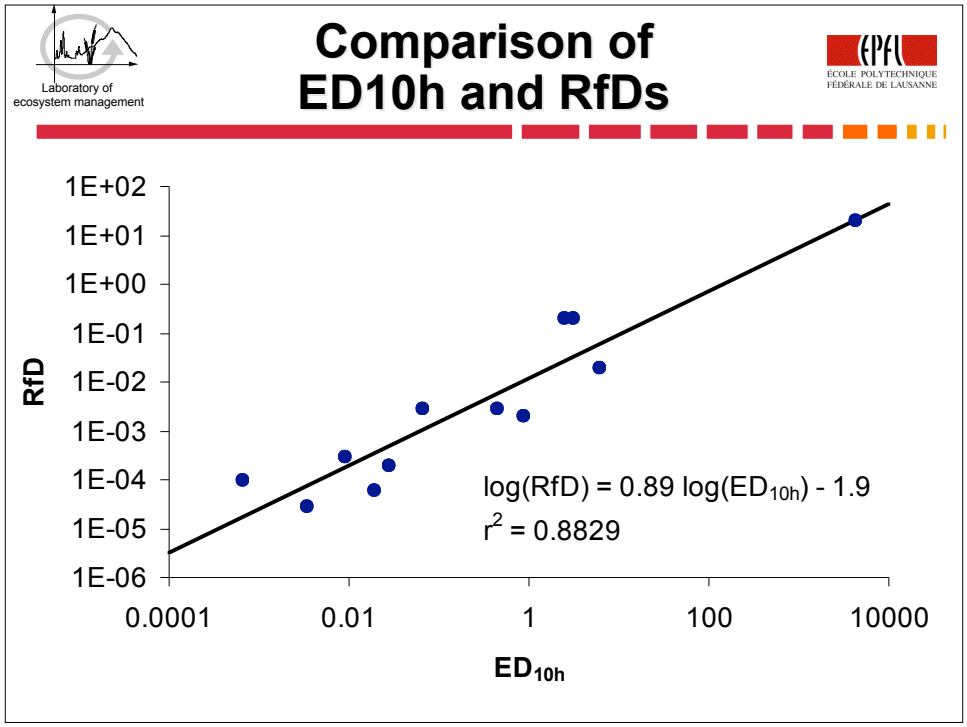
Correlation between ED10a and LOAELa
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
ED10a = 0.3 * LOAELa
Log ED10a
Log LOAELa
6
4
2
0
-2
-1
0
1
2
3
4
5
n = 9, R² = 0.99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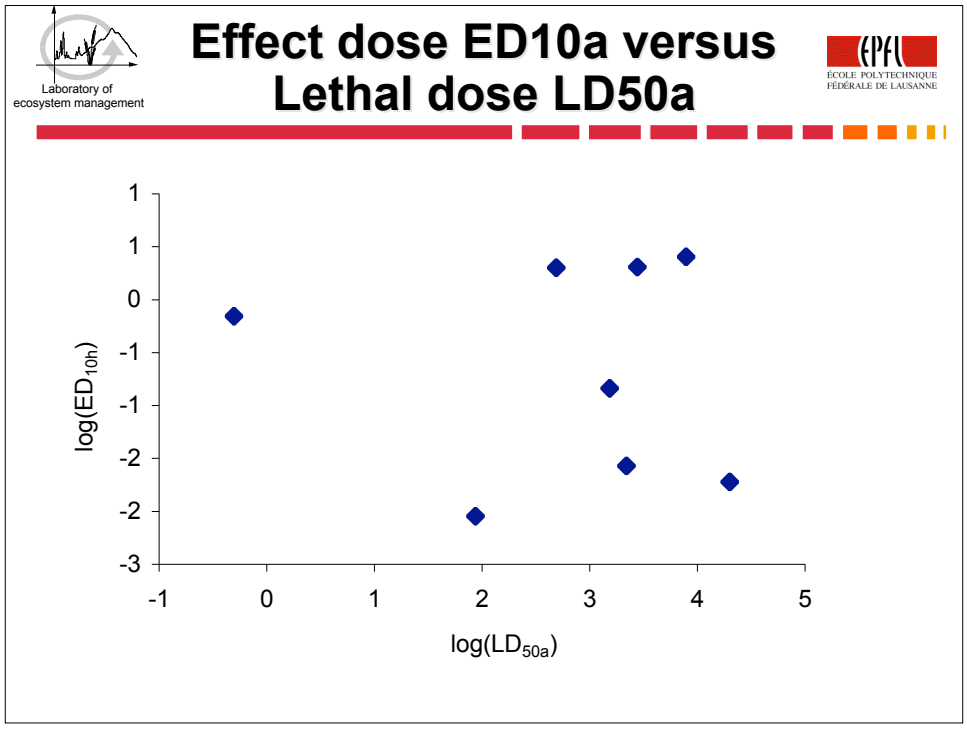
Comparison of ED10h and RfDs
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
1E+02
1E+01
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
RfD
0.0001
0.01
1
100
10000
ED10h
log(RfD) = 0.89 log(ED10h) - 1.9
r2 = 0.8829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Effect dose ED10a versus Lethal dose LD50a
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
1
1
0
-1
-1
-2
-2
-3
log(ED10h)
-1
0
1
2
3
4
5
log(LD50a)

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Compatibility between approaches

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Unit risks versus epidemiologic approaches !

Impacts of particles:

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Effect factors: Particles

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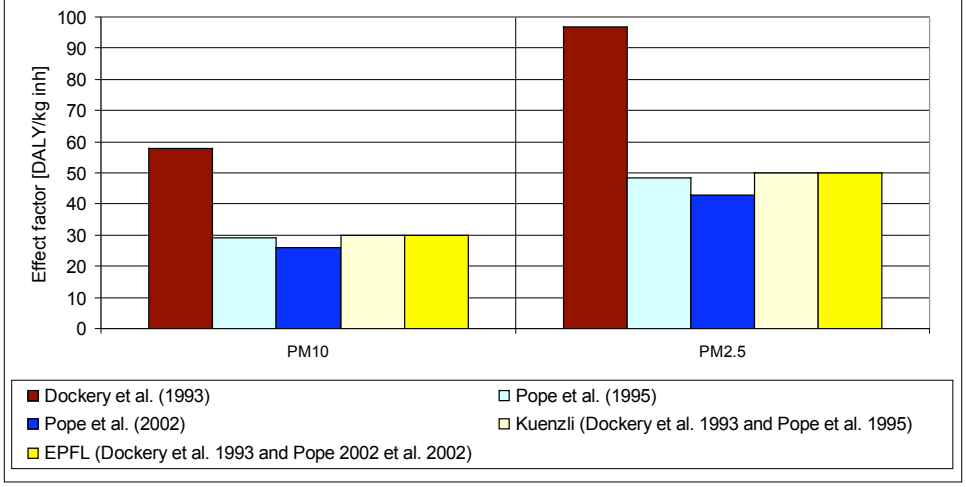

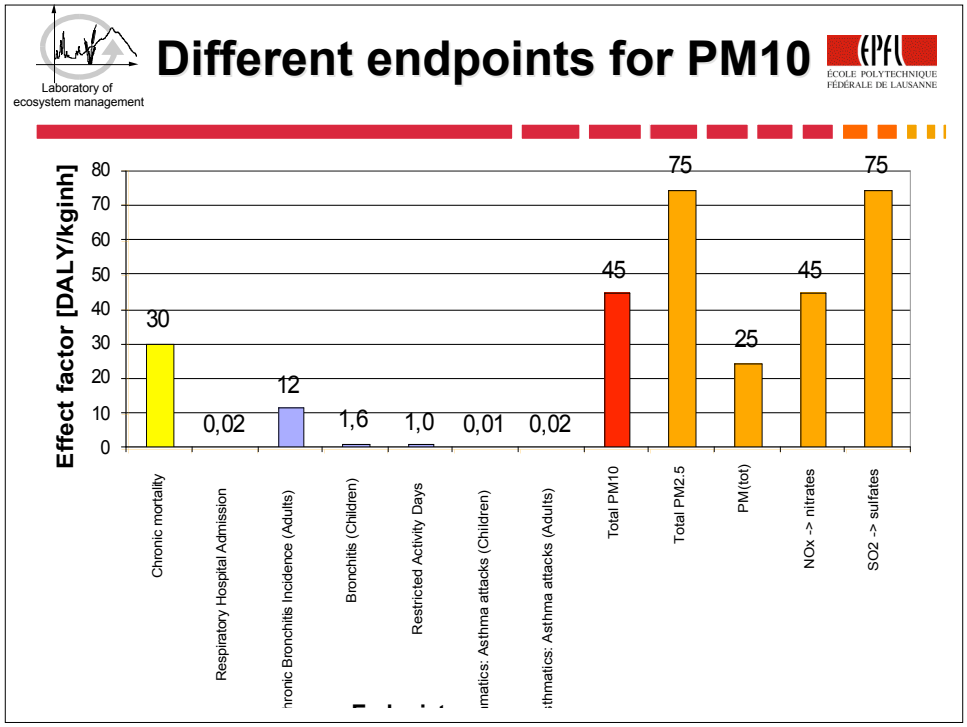
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Different endpoints for PM10
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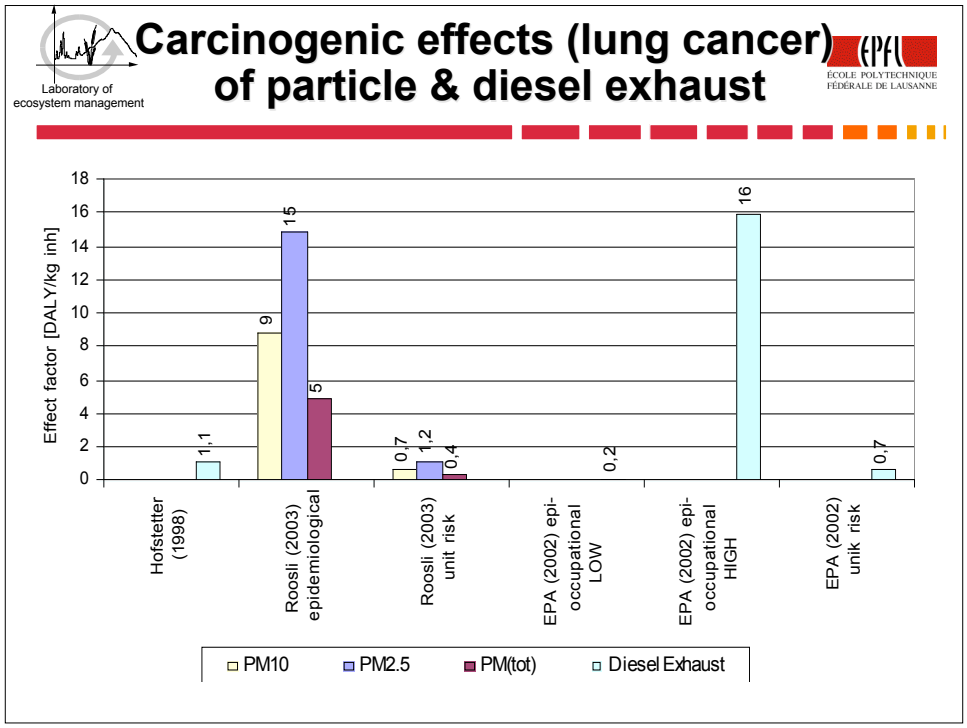
Effect factor [DALY/kginh]
80
70
60
50
40
30
20
10
0
30
0,02
12
1,6
1,0
0,01
0,02
45
75
25
45
75
Chronic mortality
Respiratory Hospital Admission
Bronchitis (Children)
Restricted Activity Days
Total PM10
Total PM2.5
PM(tot)
NOx -> nitrates
SO2 -> sulfates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Carcinogenic effects (lung cancer) of particle & diesel exhaust
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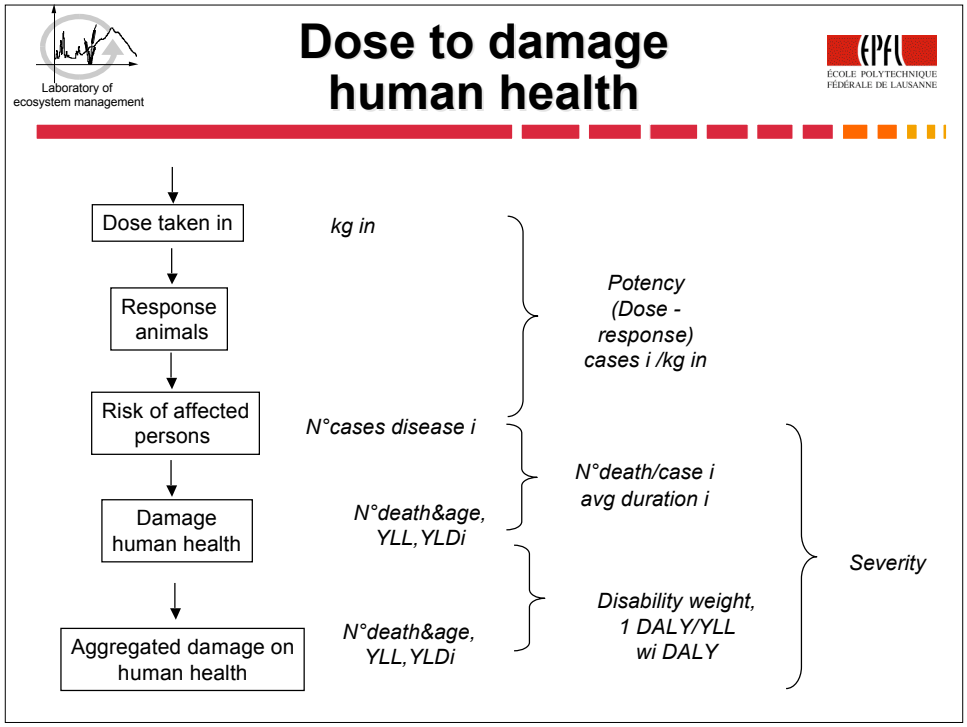
Effect factor [DALY/kg inh]
18
16
14
12
10
8
6
4
2
0
1,1
9
15
5
0,7
1,2
0,4
0,2
16
0,7
Hofstetter (1998)
Roosli (2003) epidemiological
Roosli (2003) unit risk
EPA (2002) epi-occupational LOW
EPA (2002) epi-occupational HIGH
EPA (2002) unik risk
PM10
PM2.5
PM(tot)
Diesel Exhaust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Dose to damage human health
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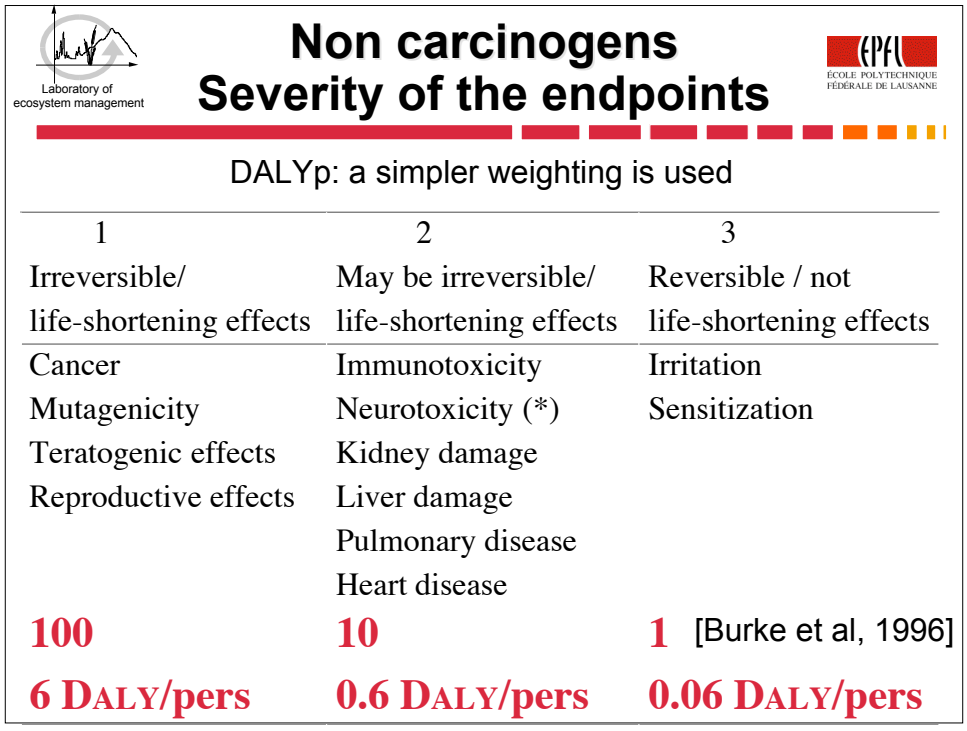
Dose taken in
Response animals
Risk of affected persons
Damage human health
Aggregated damage on human health
kg in
N°cases disease i
N°death&age, YLL, YLDi
N°death&age, YLL, YLDi
Potency (Dose - response) cases i /kg in
N°death/case i avg duration i
Disability weight, 1 DALY/YLL wi DALY
Severity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Non carcinogens
Severity of the endpoints
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DALYp: a simpler weighting is used
1
Irreversible/ life-shortening effects
Cancer
Mutagenicity
Teratogenic effects
Reproductive effects
100
6 DALY/pers
2
May be irreversible/ life-shortening effects
Immunotoxicity
Neurotoxicity (*)
Kidney damage
Liver damage
Pulmonary disease
Heart disease
10
0.6 DALY/pers
3
Reversible / not life-shortening effects
Irritation
Sensitization
1 [Burke et al, 1996]
0.06 DALY/pers

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Cancers severity

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Type of Cancer	Disability			Death			Disability + Death
	W [-]	D [yr. lost/inc.]	$YLD_p = W \cdot D$ [yr lost/inc.]	L [yr. lost]	N [inc.]	$YLL_p = L/N$ [yr. lost/inc.]	$DALY_p = YLD_p + YLL_p$ [yr. lost/inc.]
Mouth and oropharynx	0.145	4.3	0.62	3.2E+06	1.1E+06	2.9	3.5
Oesophagus	0.217	1.7	0.37	3.4E+06	3.8E+05	8.9	9.3
Stomach	0.217	2.9	0.63	7.0E+06	1.1E+06	6.5	7.2
Colon and rectum	0.217	3.7	0.80	3.9E+06	9.9E+05	3.9	4.7
Liver	0.239	1.6	0.38	6.3E+06	5.4E+05	11.6	12.0
Pancreas	0.301	1.2	0.37	1.5E+06	1.9E+05	7.9	8.3
Trachea, bronchus, lung	0.146	1.8	0.26	8.3E+06	1.1E+06	7.9	8.2
Melanoma	0.045	4.2	0.19	5.1E+05	1.7E+05	3.1	3.2
Breast	0.069	4.2	0.29	3.8E+06	1.1E+06	3.6	3.9
Cervix uteri	0.066	3.8	0.25	2.7E+06	4.5E+05	6.0	6.2
Corpus uteri	0.066	4.5	0.30	5.8E+05	3.1E+05	1.9	2.2
Ovary	0.081	3.4	0.28	1.3E+06	2.0E+05	6.4	6.7
Prostate	0.113	4.2	0.47	1.1E+06	6.8E+05	1.6	2.1
Bladder	0.085	4.2	0.36	9.8E+05	4.6E+05	2.1	2.5
Lymphomas and myeloma	0.089	3.5	0.31	3.0E+06	4.2E+05	7.2	7.5
Leukemia	0.112	3.1	0.35	4.4E+06	3.1E+05	14.3	14.6
Other cancers*	0.809	n.a.		1.3E+07	1.0E+06	13.0	13.0
Average							6.7

Due to difficulty to determine human endpoint, taken the average for all cancers

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Severity

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Main challenges:

- Dose-response for animal → human endpoints

- No severity = (Implicit) weighting in LCA, when summing up accross substances assume equal severity !! Not ISO compatible

- Report death, N°cases, YLL, YLD separately

- Disability weight optionals, new approaches to establish them

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Relationship animal endpoint - human

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Alternatives

- Stay at separate endpoints for animals (Owens)

- Endpoint animals = endpoint humans ? No !

- Start from human evidences and link it back to or use animal dose-response.

a) If similar endpoints human-animals = lower uncertainty

b) If different endpoints human-animals = high uncertainty in dose-response

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Example carbon tetrachloride

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Strong humans evidences	YLL/incidence years	Duration years	Disability weight	YLD	DALY
Cirrhosis	17	7.8	0.33	2.6	19.6
Hepatitis	2.14	0.17	0.20	0.04	2.18

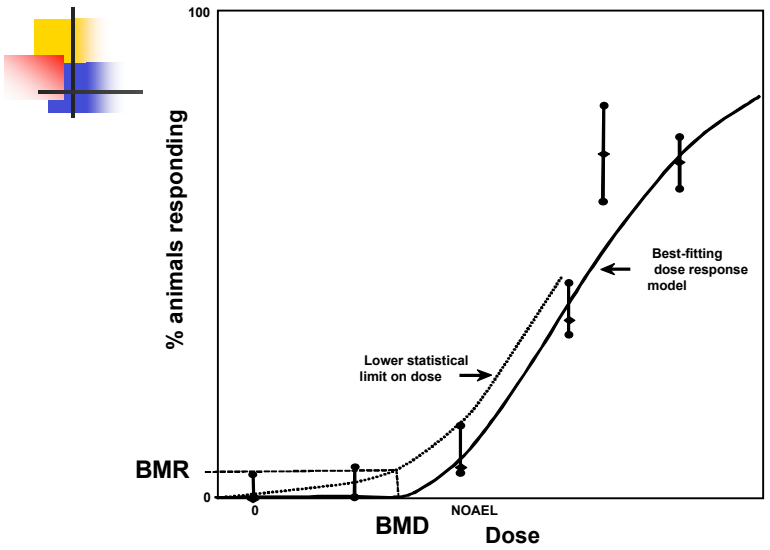
Some Comments on LCIA for Noncancer Effects

Lorenz Rhomberg, Ph.D.
Gradient Corporation
Cambridge, MA
lrhomberg@gradientcorp.com

$$IMPACT = \left[\begin{matrix} Pop'n. \\ Exposed \end{matrix}\right] \times \left[\begin{matrix} Avg. \\ Exposure \end{matrix}\right] \times \left[\begin{matrix} Risk\ per \\ person-unit\ Exposure \end{matrix}\right]$$

$$\frac{IMPACT}{unit\ emission} = \left[\frac{[\text{Pop'n. Exposed}] \times [\text{Avg. Exposure}]}{\text{unit emission}}\right] \times [Risk\ per\ person-unit\ Exposure]$$

Risk must be a linear function of Exposure
(in the range of interest)



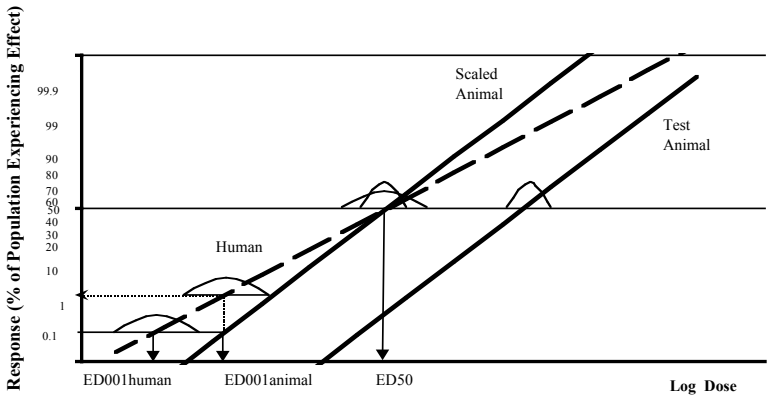
Source: US EPA, 1995. The use of the benchmark dose approach in health risk assessment. Risk Assessment Forum,
Office of Research and Development, Washington, DC. EPA/630/R-94/007.

For Noncancer Effects

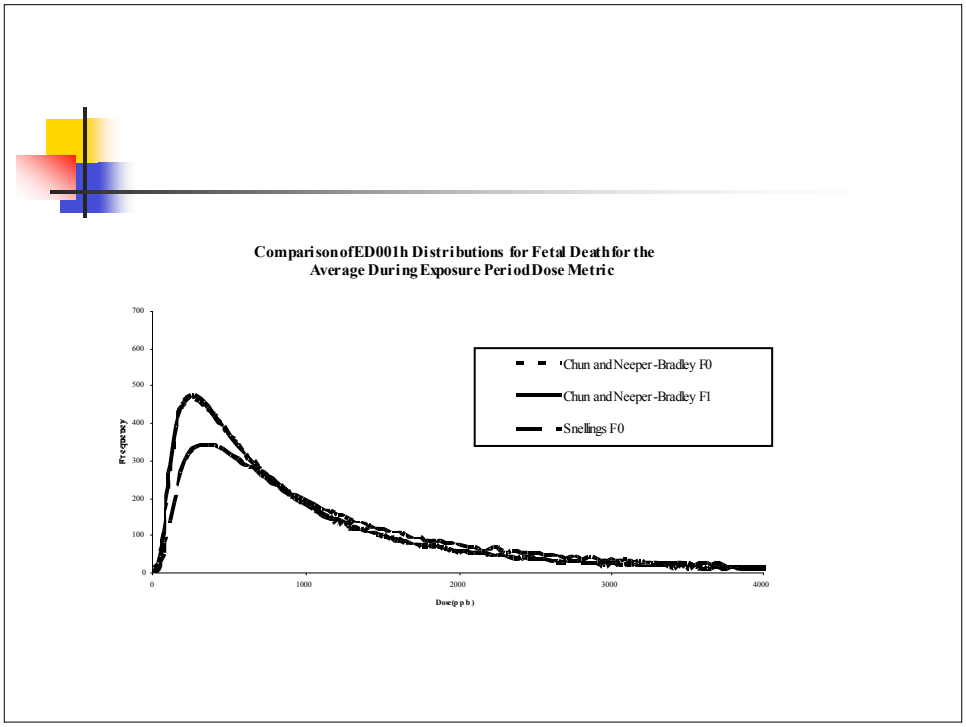
- Threshold effects; nonlinear dose-response
- Traditional approach focuses on identifying a dose-rate likely to be "safe" (and not on dose-response)

LCIA Needs for Assessing Noncancer Effects

1. An approach to nonlinear dose-response in humans
2. Estimates of the numbers of people exposed at different levels

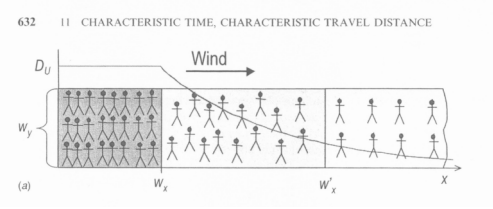


Source: SJS Baird *et al.*, SRA, 2000



The challenge for exposure analysis:
to express the population distribution of exposure
(per unit of emissions, without specific times and places).

Air Emissions



$$\text{Population-based potential dose} = \iint P(x, y) \times \text{ADD}(x, y)\, dx\, dy \qquad (11.8)$$

where P is the population density (persons/m^2) and ADD is the dose per person (mg/kg-d). In this equation, both the dose per person and the population density can vary spatially.

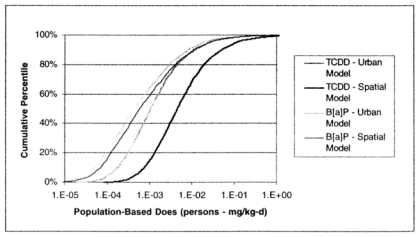
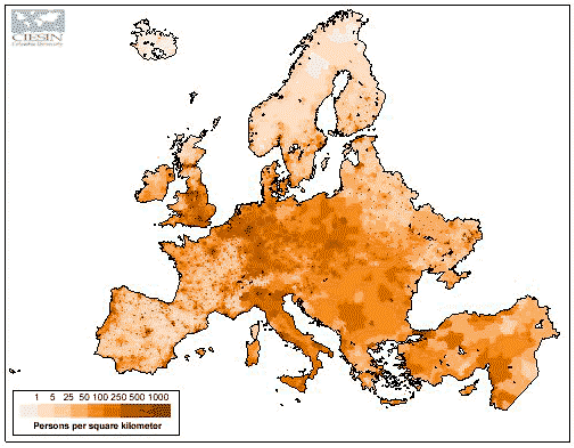


Figure 11.8 Cumulative percentile distribution of population-based potential dose for each calculation method for TCDD (a chemical with a long characteristic travel distance, CTD).

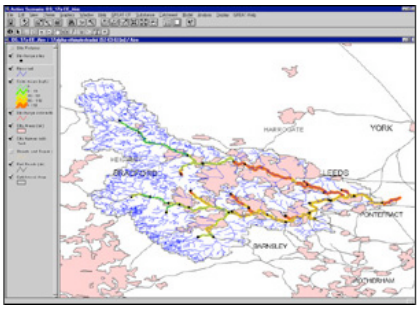
Source: Bennett, DH; McKone, TE; Kastenberg, WE. 2002. Characteristic time, characteristic travel distance, and population-based potential dose in a multimedia environment: A case study. Human and Ecological Risk Assessment: Theory and Practice (Ed.: Paustenbach, DJ). John Wiley & Sons, Inc.

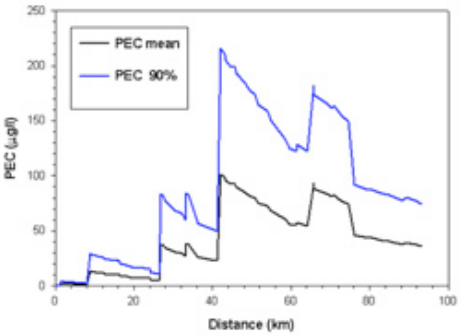
Europe Population Density, 1995



Source: http://sedac.ciesin.columbia.edu/plue/gpw/europe.html

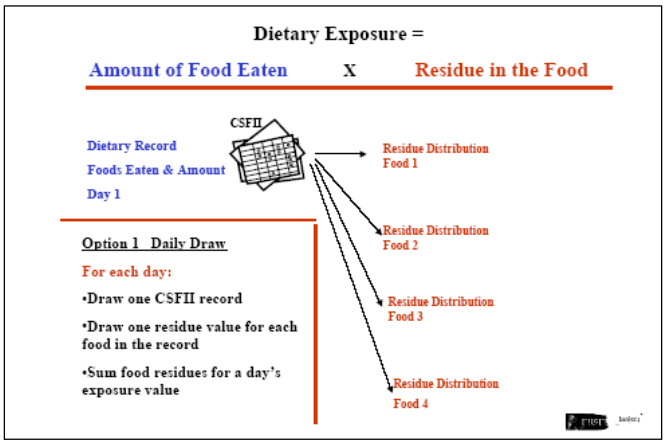
Surface Water Emissions





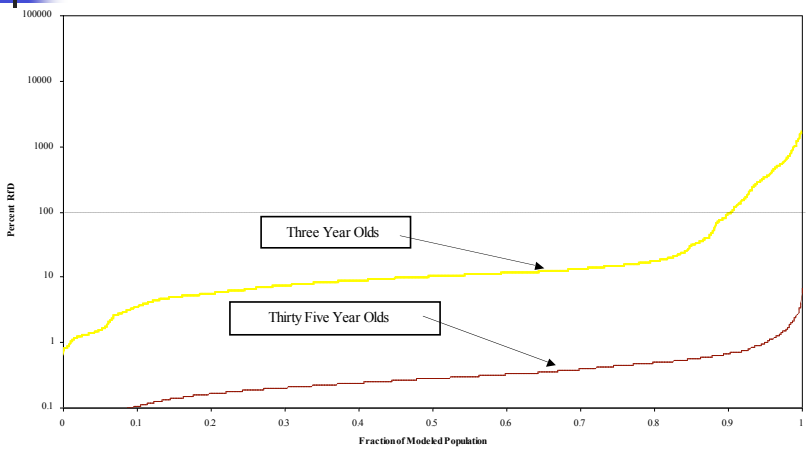
Source: www.great-er.org

Dietary Exposures



Source: The Lifeline Group

Distribution of %RfD Associated with Alpha Exposure at Two Ages



Source: The Lifeline Group

Combining Risk and Exposure Distributions